

5

**Microscopy system, microscopy method, and  
a method of treating an aneurysm**

---

10

**Background of the invention.**

**1. Field of the invention.**

The invention relates to a microscopy system and a  
microscopy method which may be in particular used for  
15 observing an emission of fluorescent light at wavelengths  
of the near infrared and/or infrared. Further the invention  
relates to a method of treating an aneurysm.

Fluorescent substances and fluorescent dyes showing a  
20 fluorescence at wavelengths in a region of the near  
infrared or infrared are used in medical applications for  
various purposes such as visualizing particular types of  
tissue, tissue structures and tissue functions. Herein, a  
fluorescent substance or dye or a precursor of such  
25 fluorescent substance or dye is applied to a patient under  
examination. The dye accumulates in particular types of  
tissue and tissue structures, and by observation of the  
fluorescent light such types of tissue and tissue  
structures, respectively, may be visualized and identified  
30 by an observer. Optical tools are used to visualize the  
some times weak intensities of fluorescent light.

**2. Brief description of related art.**

One example of a suitable fluorescent substance is  
35 indocyanine green (ICG). From the article by T. Kuroiwa et  
al., "Development and Clinical Application of Near-Infrared  
Surgical Microscope: Preliminary Report", Minim Invas

Neurosurg 2001; 44: 240-242, there is known a method and system for observing the fluorescence of this substance. An excitation wavelength of the fluorescence of the substance is about 780 nm, and a fluorescent emission wavelength is about 835 nm. For an observation of a tissue in which ICG has accumulated by a microscope, the tissue is illuminated with light of a main wavelength of 800 nm of a laser light source or of a halogen lamp. In a beam path of the illuminating light there is positioned a band-pass filter which allows only light having wavelengths between 760 nm and 810 nm which is light for exciting the fluorescence to pass there-through. The tissue is imaged onto a camera by a microscopy optics wherein a further band-pass filter allowing only light having wavelengths between 820 nm and 920 nm which is fluorescent emission light of ICG to pass there-through. An observation of images detected by the camera allows to identify those regions of the tissue in which the fluorescent substance has accumulated. It is, however, not possible to perceive surrounding regions of this tissue. Such surrounding regions would emit visible light under a suitable illumination. However, such illumination with visible light is not possible since the laser light source does not provide such light, and the band-pass filter in the beam path of the light source blocks such visible light from incidence on the tissue. A surgeon performing a surgical treatment of the tissue region has to illuminate the tissue region with visible light for perceiving an optical image of the tissue region with visible light in a first step, and he has to observe the fluorescent image thereafter for perceiving the fluorescent light in a subsequent second step. Further, an illuminating light beam of the laser light source and an illuminating beam for illuminating the tissue region with visible light are incident on the surface region under different angles such that both light beams generate different types of shadows on the tissue region. Such

different shadows render it more difficult to correctly associate regions of the fluorescent image with regions of the visible image of the tissue region.

- 5 Such procedure is complicated and requires a high power of concentration of the observer since he must remember the image previously perceived at the respective different type of illumination.
- 10 The article of T. Kuroiwa et al., discloses an application of the ICG fluorescence for obtaining information about deep-seated tissues. The excitation and emission wavelengths of ICG lie within the "optical window" of tissue, where absorption attributable to endogenous
- 15 chromophoreous is low. Near infrared light can therefore penetrate tissue to a depth of several millimeters to a few centimeters. According to the article, a near infrared fluorescence of vessels on the brain surface was observed through the dura mater. The article concludes that a
- 20 stronger fluorescence emitted from the ICG will be necessary for the application to have practical use even for imaging venous vessels.

- A cerebral or intra-cranial aneurysm is a dilatation of an
- 25 artery in the brain that results from a weakening of the inner muscular layer of a blood vessel wall. The vessel develops a "blister-like" dilation that can become thin and rupture without warning.

- 30 The vascular dilation itself is referred to as an aneurysm sac, and an entrance area that leads from the parent artery to the aneurysm sac is referred to as aneurysm neck. According to a conventional surgical technique of medical therapy of the aneurysm, a clip is used to close the
- 35 aneurysm sac. Thereafter, the surgeon has to verify that the aneurysm sac is completely closed and that a sufficient

vascular flow is guaranteed in the parent artery and surrounding vessels.

According to a conventional technique the vascular flow is assessed by x-ray angiographie. For performing x-ray angiography, the surgical microscope which must be used for performing the surgery and positioning the clip has to be dismantled first, the x-ray apparatus has to be mounted thereafter, and the surgeon has to leave the room while the x-ray images are recorded. Development and interpretation of the x-ray image will take some ten minutes. Intra-operative x-ray angiography is often not used in practice for blood flow assessment due to the long duration until interpretation of the results. Further, an imaging resolution achievable with x-ray angiography is not sufficient for assessing blood flow in small vessels. Further, a complication rate associated with x-ray angiography is considered to be relatively high due to the necessity of applying a corresponding contrast agent via a catheter into an artery of the patient.

#### **Summary of the invention.**

It is an object of the present invention to provide a method of surgical treatment of an aneurysm and allowing intra-operative observation and documentation of blood flow in small arterial vessels.

It is a further object of the present invention to provide a microscopy system and a corresponding microscopy method which improve a performance of microscopic imaging in combination with a fluorescence at infrared or near infrared wavelengths.

According to a first aspect of the invention there is provided a method of treating an aneurysm of a patient, the method comprising clipping the aneurysm, injecting

indocyanine green into the patient generating at least one fluorescence image of at least one artery adjacent to the clipped aneurysm, and assessing vascular blood flow of the at least one artery based on the at least one fluorescence image.

The method using ICG as a fluorescent substance for assessing the blood flow is simple and offers real time information on the patency of arterial and venous vessels of all relevant diameters including small arteries such as arteries of a diameter less than 0.5 mm, that are visible to the surgeons eye. An interpretation of the recorded images may be finished within one minute or less. Since ICG is not metabolized in the body and is excreted by the liver with a plasma half time of three to four minutes, the method may be repeated after five to ten minutes.

A detailed illustration of the method is given in the article of A. Raabe et al., Neurosurgery, 132, volume 52, number 1, January 2003 ([www.neurosurgery-online.com](http://www.neurosurgery-online.com)). The full disclosure of this article is incorporated herein by reference.

According to a second aspect of the invention there is provided a microscopy system and method having an improved performance in microscopic imaging fluorescent light images at infrared or near infrared wavelengths.

According to a further embodiment the invention provides a microscopy system for visualizing a fluorescence of indocyanine green (ICG) wherein the microscopy system comprises a microscopy optics, a display system and an illumination system. The microscopy optics comprises a first beam path for imaging an object region onto a light detecting component of the first camera using light of a first range of wavelengths comprising an emission

wavelength or fluorescent wavelength of indocyanine green. Thus, the first beam path is provided for generating fluorescent light images of the object region. The microscopy optics further comprises a second beam path for providing a magnified representation of the object region with light of wavelengths of a second range of wavelengths including at least visible light. Thus, the second beam path is provided for generating images of the object region in a visible region of the spectrum.

The display system displays the fluorescent light images superimposed with the visible light representations such that a user may perceive both the fluorescent light images and the visible light representations at a same time.

The illumination system provides at least one illuminating light beam directed to the object region. The at least one illuminating light beam includes light of the visible portion of the spectrum, in particular blue light and/or yellow light, and the illuminating light beam also includes light with an excitation wavelength of indocyanine green.

The inventors recognized that it is possible to observe the object region with both visible light and fluorescent light at a same time when using the system illustrated above. It is not necessary to perform a conventional switching between observations under visible light and observations under fluorescent light. Further, the provision of the visible light and the excitation light in a common illuminating light beam prevents different shadows generated with excitation light and visible light on a structured object, and substantially the same illumination conditions are provided for both the excitation light and the visible light.

According to a preferred embodiment the at least one illuminating light beam is generated by one single light source generating both the visible light and the light of an excitation wavelength of indocyanine green. The light source may comprise light sources such as a xenon lamp or a halogen lamp.

Herein, the inventors recognized that suitable light sources which are conventionally used for generating illuminating light beams of visible light are able to generate excitation light of indocyanine green with a sufficient intensity for recording fluorescent light images of the object region with a suitable camera. Provision of a separate light source, such as a laser light source, for excitation of the fluorescence of the indocyanine green, as it was used in the prior art, is no longer necessary.

According to a preferred embodiment, a filter is disposed in a beam path of the illuminating system which filter substantially blocks light at emission wavelengths of the fluorescent emission wavelengths of indocyanine green. It is thus possible to record fluorescent images of a high contrast.

According to a preferred embodiment the microscopy system is used in the method of treating the aneurysm. According to a further embodiment, the illumination system comprises a thermal protective filter eliminating light from the illuminating light beam having wavelengths such that they are not perceived by the human eye or that they are perceived with only a low efficiency and which mainly contribute to heating of the object under examination. Thus, an unnecessary heating of the object is effectively prevented. The thermal protective filter may be removed from the beam path of the illumination system when fluorescent light images of the object are to be recorded.

The filters of the illumination system may be transmissive filters or reflective filters.

- 5 According to a preferred embodiment the microscopy system is used in the method of treating the aneurysm.

According to a further embodiment the invention provides a microscopy system for visualizing a fluorescence of a  
10 fluorescent substance wherein the microscopy system comprises a microscopy optics, an image memory and a display system. The microscopy optics again comprises a first beam path for imaging a fluorescent light image of the object region onto a camera, and a second beam path for  
15 providing a representation of the object region with light including at least visible light.

The image memory is configured for storing image data representing fluorescent light images of the object region  
20 recorded during a time interval.

The display system is configured to display the visible light image of the object region superimposed with a series of images generated from the previously recorded and stored  
25 image data.

It is thus possible to display rapidly changing configurations of the object region which are visible in the fluorescent image merely during a short time. Such  
30 rapidly changing configurations in the image are displayed in the overlaying relation with the visible light image of the object region at a time after the rapid change in the configuration has already happened. The rapidly changing configurations may be repeatedly displayed or they may be  
35 displayed in slow motion.



According to a preferred embodiment the microscopy system is used in the method of treating the aneurysm.

5 For this purpose indocyanine green is applied to the patient by intravenous injection, and the process of the fluorescent substance entering the parent and surrounding vessels is observed with the camera. The process of entering the vessels may take 0.5 to 2 s. Herein it is important that the blood with the fluorescent substance  
10 enters the relevant vessels at a substantially same time. If the fluorescence will become visible in a particular vessel later than in surrounding vessels this will be indicative that the particular vessel is partially blocked.

15 The above illustrated assessment of vascular flow may be easily performed by repeatedly displaying the image data recorded during the respective time interval and/or by displaying the image data in slow motion and in superposition with the visible light image of the object  
20 region.

If the fluorescent substance accumulates in the aneurysm sac this will be indicative of a non-complete blocking of the aneurysm sac with the clip.

25 Preferably, the microscopy system comprises a controller for analyzing the stored images with respect to a beginning process of the fluorescent substance entering the relevant vessels. Such start of the process may be derived from a  
30 time at which intensities of the fluorescent light exceed a threshold at some locations in the images.

The controller may also determine an end of such process by analyzing changes in fluorescent light intensities from  
35 image to image, and if a saturation of increasing intensities is detected, an end of the process of

fluorescent substances entering the relevant vessel will be decided. The controller may then supply only a subset of the stored image data to the display system. The subset will include those data recorded after the start and/or  
5 before the end of the process of fluorescent substances entering the relevant vessels.

According to a preferred embodiment the microscopy system is used in the method of treating the aneurysm.

10

According to a further embodiment the invention provides a microscopy system for visualizing a fluorescent substance wherein the microscopy system comprises a microscopy optics, an illumination system and a display system. The  
15 microscopy optics again comprises a first beam path for imaging a fluorescent light image of the object region onto a camera, and a second beam path for a magnified imaging of the object region with visible light. The display system again displays the visible light image of the object region  
20 superimposed with the fluorescent light image of the object region generated from image data recorded with the camera.

The illumination system provides an illuminating light beam directed to the object region wherein the illuminating  
25 light beam includes light at an excitation wavelength of the fluorescent substance. The illuminating system comprises a light modulator for modulating an intensity of the light at the excitation wavelengths of the fluorescent substance. This results in a modulation of the fluorescence  
30 of the substance in time, and the fluorescent images detected by the camera also vary in time. Such known variation in time of the intensities is taken into account when generating the fluorescent light images with a high contrast. For instance, locations in the images detected by  
35 the camera may be determined which show varying intensities. Only those locations may be then represented

with a higher intensity in the generated fluorescence image.

According to a preferred embodiment the microscopy system  
5 is used in the method of treating the aneurysm.

According to a further embodiment the invention provides a  
microscopy system comprising a microscopy optics, an  
illumination system and a controller. The microscopy optics  
10 again comprises a first and a second beam path which may  
traverse a common objective lens of the microscopy optics.  
The first beam path images the object region onto a camera  
for generating image data representing the object region.  
The illumination system provides an illuminating light beam  
15 directed to the object region. A filter is disposed in a  
first position within the beam path of the illuminating  
light beam. The illuminating system further comprises an  
actuator for changing the position of the filter from a  
second position in which the filter is not disposed within  
20 the beam path to the first position.

The controller is configured to analyze the image data  
recorded with the camera, and to control the actuator for  
displacing the filter from the first position to the second  
25 position based on such analysis. the analysis may comprise  
a determination of light intensities at particular portions  
of the images recorded with the camera.

Preferably the filter is a filter of such type that it  
30 eliminates light having wavelengths greater than a  
predetermined wavelength from the illuminating light beam.  
The predetermined wavelength is preferably greater than  
690 nm. Further, the predetermined wavelength is preferably  
smaller than 800 nm.

35

With such system it is possible to provide two different illumination modes wherein the system is automatically switched from one mode to the other mode based on an analysis of the images of the object region detected by the camera.

A preferred application of such microscopy system is in combination with the above-illustrated process of a fluorescent substance entering some particular vessels of interest. An end of such process is automatically detected. It is then possible to operate the system in a first illumination mode during the recording of the fluorescent light images wherein the illuminating light beam includes infrared light for excitation of the fluorescence. When the end of the process is detected the thermal protective filter is automatically disposed in the beam path of the illuminating system such that the system is operated in a second illumination mode in which thermal radiation including infrared light is removed from the illuminating light beam for preventing unnecessary thermal heating of the inspected object region.

According to a preferred embodiment the microscopy system is used in the method of treating the aneurysm.

According to a further embodiment the invention provides a microscopy system comprising a microscopy optics having a first beam path for generating fluorescent light images of the object region and a second beam path for providing a representation of the object region as seen with visible light, and a display system for displaying the presentations generated from the fluorescent images in superposition with visible light representations of the object regions. The microscopy system further comprises a controller which is configured to analyze the fluorescent light images for detecting coherent portions of the image

in which intensities of the fluorescent light exceed a threshold. The controller then generates image data representing the fluorescent light image such that only peripheral lines of the coherent portions are visible in the representation. The user may then identify those portions of the object region in which the fluorescent intensity exceeds the threshold by perceiving the peripheral line. At the same time it is possible for the user to perceive an interior of the coherent portion as a representation of the visible light image.

According to a preferred embodiment the microscopy system is used in the method of treating the aneurysm.

According to a further embodiment the invention provides a microscopy system having an interferometer apparatus for generating depth profile data representing an intensity of radiation of an analyzing light beam received back from an object. The analyzing light beam is directed to the object, wherein a location to which the analyzing light beam is directed on the object may be selected by control of a beam scanner.

Generation of such depth profile data is conventionally time consuming and, in particular, it is conventionally necessary to generate depth profile data at substantially all scanning positions within an object field of the microscopy system.

According to the invention, a microscopy system having an interferometer apparatus is provided, wherein the microscopy system comprises a camera for recording an image of the object with fluorescent light, and wherein a controller is provided for analyzing the recorded image and for determining an analyzing portion within the image. The analyzing portion comprises at least one coherent portion

of the image recorded with the camera in which an intensity in the image exceeds a threshold. The controller may control the interferometer apparatus such that the depth profile data are only generated at locations within the analyzing region.

It is thus possible that the controller selects from the fluorescent light image a tissue type of interest for the particular application, such as cancerous tissue, in dependence of the fluorescent image. Those portions in the image in which the tissue type of interest is present are used as the analyzing region, and depth profile data are generated only for locations within the analyzing region. In portions outside of the analyzing region depth profile data are not generated.

It is thus not necessary that the user has to determine those portions at which depth profile data should be generated, and it is possible to obtain the depth profile data for portions of interest in a relatively short time.

Preferably, the interferometer apparatus for generating the depth profile data comprises an optical coherence tomography (OCT) apparatus.

25

#### **Brief description of the drawings.**

The forgoing as well as other advantageous features of the invention will be more apparent from the following detailed description of preferred embodiments of the invention with reference to the accompanying drawings. Herein

Figure 1 shows a schematic representation of beam paths of a microscopy system according to an embodiment of the present invention;

35

Figure 2 shows transmission characteristics of filters which may be used in the microscopy system according to figure 1;

5 Figure 3 is a flowchart for illustrating a microscopy method according to an embodiment of the invention;

10 Figure 4 is a schematic representation of a further embodiment of the microscopy system according to the invention;

15 Figure 5 is a schematic representation of images generated with the microscopy system of figure 4; and

20 Figure 6 is a detailed partial illustration of an interferometer apparatus provided in the microscopy system according to figure 4.

#### **Detailed description of exemplary embodiments.**

Figure 1 schematically shows a microscopy system 1 comprising a microscopy optics 3 including an objective lens 5 having an optical axis 7. An object 9 to be inspected is disposed in an object plane of objective lens 5. Light emanating from the object 9 is transformed by the objective lens 5 to form a parallel beam 11 in which two zoom systems 12, 13 are disposed at a distance from the optical axis 7. The zoom systems 12, 13 use partial beams 14 and 15 of the parallel beam 11 and supply the partial beams 14, 15 to oculars 16 and 17 through deflecting prisms (not shown in figure 1) of a body of a tube of the microscopy system 1. A user may perceive a magnified representation of the object 9 as an image when looking into the oculars 16, 17 with his left eye 18 and right eye

19, respectively. The image perceived with the left eye 18 corresponds to an image when looking onto the object under an angle  $\alpha$  with respect to the optical axis, and the image perceived with the right eye 19 corresponds to an image when looking onto the object 9 under an angle  $-\alpha$  with respect to the optical axis 7, such that the user perceives a stereoscopic image of the object 9 with his both eyes 18, 19.

10 A partially transmissive mirror 21 is disposed in the partial beam 15 for branching off a portion of the light thereof as a beam 23. Beam 23 is splitted with a further beam splitter 25 to form beams 27 and 29. Beam 27 is supplied to a light sensitive element of a camera 32 through a camera adapter optics 31 such that the camera 32 detects an image of the object 9 under an observation angle  $-\alpha$  with respect to optical axis 7. The images detected with camera 32 are transmitted as image data through a data line 33 to a controller 35.

20 A beam 39 is branched off from partial beam 14 by a partially transmissive mirror 37. Beam 39 is supplied to a light sensitive element of a further camera 43 through a camera adapter optics 41 such that camera 43 detects images of the object 9 under an observation angle  $\alpha$  with respect to the optical axis 7. The images detected by camera 43 are supplied as image data to controller 35 through a data line 45. The controller transmits the images detected by cameras 32, 43 as image data through a line 47 to a head mounted display 49 which is carried by a user of the microscopy system 1 at his head such that integrated displays of the head mounted display 49 which are schematically indicated with reference numerals 51 and 52 in figure 1 provide respective images which may be perceived by the user with his left and right eyes, respectively.



Thus, a user who is not in a position of directly looking into the oculars 16, 17 may also perceive a stereoscopic representation of the object 9 by using the head mounted display 49 by observing representations of visible light images of object 9.

Beam 29 is supplied to a light sensitive element of a camera 55 through a camera adapter optics 53 such that camera 55 may detect an infrared image of the object. A filter 57 is disposed in beam 29. A transmission characteristic of filter 57 is schematically illustrated as a line 58 in figure 2a. A vertical line 59 in figure 2a further represents a maximum of an excitation spectrum of the fluorescent substance indocyanine green (ICG) at 780 nm. A vertical line 60 in figure 2a represents a corresponding maximum of a fluorescent emission spectrum of ICG at 835 nm. The transmission characteristic 58 of filter 57 shows a threshold 61 at about 810 nm. The filter 57 is substantially non-transmissive at wavelengths below the threshold, and the filter 57 is substantially transparent at wavelengths above the threshold. The camera 55 thus detects images of the object 9 which represent a distribution of the fluorescent substance within the object 9, provided that the fluorescence of the substance is excited with an illumination system 63 of the microscopy system 1 as further illustrated below.

The images detected with camera 55 are transmitted through a data line 65 to the controller 35. The controller 35 transmits the images detected with camera 55 as image data through a data line 67 to a LCD display 69. LCD display 69 represents the image data as an image which is superimposed with partial beam 15 by a collimating optics 70 and a partially transmissive mirror 68. The image of the display 69 may be perceived by the eye 19 of the user in superposition with the direct optical image of the object

9. The LCD display 69 represents the infrared light intensity distribution detected by camera 55 in a visible color such as green color. Green color may be advantageously used for representing the infrared image since human tissue forming the object 9 usually comprises green color in a relatively low amount.

The controller performs a data processing of the image data transmitted to display 51 of head mounted display 49 such that the display 51 displays the infrared light images detected by camera 55 superimposed with the visible light images detected by camera 32. Thus, the user wearing the display 49 at his head may also perceive with his right eye a superimposed representation of visible light images and infrared light images of the object.

Even though it is not illustrated in figure 1 for ease of reference and clarity, a further beam may be branched off from partial beam 14 supplied to the left eye 18. Such further beam may be supplied to a further infrared camera for generating images which are superimposed with the partial beam 14 of visible light as illustrated above for partial beam 15, LCD display 69, collimating optics 70 and partially transmissive mirror 68. The user will then perceive a stereoscopic infrared light image of the object 9. Image data generated by such additional camera may also be supplied to display 52 of head mounted display 49 such that also head mounted display 49 provides a stereoscopic representation of a distribution of the fluorescent substance within the object 9.

The illumination system 63 comprises a halogen lamp 71 as a light source, a reflector 72 and a collimator 73, for generating a collimated light beam 74 which is directed through one or plural lenses 75 onto an entrance end 76 of an optical fiber bundle 77 for coupling light emitted from

light source 71 into the fiber bundle 77. The light is transported by fiber bundle 77 to a position close to the objective lens 5 and emanates from an exit end 78 of the fiber bundle 77. A collimating optics 79 is provided for  
5 shaping the emanating light to form an illuminating light beam 81 directed to object 9. The embodiment is not limited to using a halogen lamp as a light source. Also other light sources, such as a xenon lamp, may be used.

10 In the presentation of figure 1 the collimating optics 79 is positioned comparatively close to the objective lens 5. Nonetheless the illuminating light beam 81 is oriented with a relatively high angle with respect to optical axis 7 of objective lens 5. Such high angle between the directions of  
15 the illuminating light beam 81 and the main axis 7 of the objective lens may result in an insufficient illumination of the object. In particular in a situation where a surgical method is performed in a deep hole provided in the human body, such as in a human brain for treating an  
20 aneurysm, it may not be possible to perceive both the visible light image and the fluorescent light image in superposition with each other. For such and other applications it is preferred to use a configuration of the illuminating system in which the illuminating light beam is  
25 oriented with a low angle to the optical axis 7. This may be conventionally achieved by including the objective lens in the beam path of the illuminating light beam, i.e. the illuminating light beam passes through the objective lens, or the objective lens is provided with an aperture  
30 penetrated by the illuminating light beam.

The illuminating system 63 further comprises a filter plate 83 having two filters 84 and 85 disposed adjacent to each other. An actuator 87 controlled by controller 35 is  
35 provided for displacing the filter plate 83 in a direction indicated by double arrow 88 in figure 1 such that filter

84 is disposed in beam 74 in a first position of plate 83 and that filter 85 is disposed in beam 74 in a second position of plate 83.

- 5 A transmission characteristics of filter 84 is shown in figure 2b as a line 89 and represented in table 1 below:

Table 1

T[%]	$\lambda$ [nm]
< 05	300 – 385
= 50	395 – 410
> 85	420 – 660
> 70	420 – 770
= 70	779
= 0.1	801
< 0.01	810 - 1200

- 10 It is evident that filter 84 transmits visible light and light with wavelengths up to a flank 90 of 800 nm substantially completely and that wavelengths above flank 90 are substantially not transmitted. Filter 84 is positioned in beam 74 in applications for observing the
- 15 fluorescence of the fluorescent substance in the inspected object region 9. Flank 90 at 800 nm is at a wavelength higher than the excitation wavelength 59 of ICG such that light beam 81 both excites the fluorescence detected by camera 55, and illuminates the object region with visible
- 20 light such that the visible light image of the object may be perceived by looking into the oculars 16, 17 and by observing the images detected by cameras 32, 43.

- 25 In an application where it is not necessary to observe the fluorescence, the controller 35 drives the actuator 87 to displace filter plate 83 such that filter 85 is disposed in beam 74. A transmission characteristics of filter 84 is schematically illustrated in figure 2c as a line 91 and represented in table 2 below:

Table 2

T[%]	$\lambda$ [nm]
< 05	300 – 385
= 50	395 – 410
> 85	420 – 660
> 70	420 – 660
= 50	680 – 710
< 05	720 - 1180

It is evident that filter 85 substantially transmits  
 5 visible light up to a flank 93 of the transmission  
 characteristics 91, and that the filter is substantially  
 non-transmissive for light at wavelengths above flank 93.  
 Flank 93 is at about 710 nm. The filter 85 is used as a  
 thermal protective filter for eliminating radiation from  
 10 the illuminating light beam 81 which would otherwise result  
 in an unnecessary heating of the object 9. The flank 93 is  
 well below the maximum excitation wavelength 59 of ICG even  
 though an excitation spectrum of ICG also extends to  
 wavelengths below 710 nm. However, a fluorescence of the  
 15 substance is substantially not excited when filter 85 is  
 disposed in beam 74.

The controller further comprises an image memory 95 for  
 storing a series of images or image data representing such  
 20 images detected by camera 55. The controller 35 is further  
 configured to successively supply the image data stored in  
 memory 95 to display 69 such that display 69 displays the  
 images previously detected by camera 55 as a time series of  
 images. The series of images may be also supplied to the  
 25 head mounted display 49.

The display of the time series of the images may be  
 understood as a film representation of the infrared light  
 images. Such representation will be preferably used in a  
 30 situation where a process of the fluorescent substance

entering a vessel system allows to assess and verify structures or functions of the vessel system. At a time after the fluorescent substance has entered the vessel system the detected image will be substantially stationary in time, and substantially no additional information may be gained from further observation of the infrared light image. Since such process of entering the vessel system is of a relatively short duration of one to five seconds, a surgeon would have to watch the process with highest concentration and memorize the time dependence of the process for each vessel of interest. The possibility of storing the images detected by camera 55 during the process and the possibility to repeatedly display the stored images as a film will help the surgeon in gaining a complete impression of the observed process.

An embodiment of a method of operating the microscopy system 1 will be illustrated below with reference to the flowchart of figure 3. At a start of an imaging procedure the thermal protective filter 85 is disposed in the beam path of the illumination system 63, and the controller waits in a step S1 for a start button of a switch 97 or some other input means being operated by the surgeon or his assistant. Preferably, the start button 97 will be operated shortly before or after the injection of the fluorescent substance into the patient. In a step S3 the actuator removes the thermal protective filter 85 from the beam path and inserts fluorescent imaging filter 84 in the beam path, and in a S5 a counter n is reset. Thereafter, an image B(0) detected by camera 55 is stored as image data in memory 95. This image is also transferred by controller 35 to display 69. Display 69 displays the image such that the surgeon may perceive the image in superposition with the visible light image of the object 9 when looking into the ocular (S9). Thereafter counter n is incremented (S11), a next image B(n) is received from camera 55 and stored in memory 95

(S13), and this image  $B(n)$  is visualized by display 69 or 51 in a step S15.

Since the vessel system under observation does not contain  
 5 fluorescent substance at the start of the procedure, the  
 first detected images  $B(n)$  show substantially no  
 intensities of infrared light. The fluorescent substance  
 propagates through the body of the patient and finally  
 enters the tissue region 9 in the object field of the  
 10 microscopy objective 3 such that the images  $B(n)$  show  
 successively increasing infrared intensities. The  
 controller 35 analyses the intensities of the images  $B(n)$   
 and compares the intensities in a step S17 with a first  
 predetermined threshold. If the intensity of the latest  
 15 detected image  $B(n)$  is less than the first threshold,  
 processing is continued with step S11. If the intensity of  
 image  $B(n)$  is higher than the first threshold this is  
 indicative of a point in time used as a start of a series  
 of detected images which series will be repeatedly  
 20 displayed to the user later. The current value of counter  $n$   
 is assigned to a variable  $nstart$  in a step S19.

Thereafter the counter is incremented (S20), the next image  
 $B(n)$  is obtained and stored (S21) and displayed (S23). The  
 25 controller 35 compares in a step S25 the intensity of the  
 last detected image  $B(n)$  with the intensity of the second  
 last image  $B(n-1)$  and continues processing at step S20, if  
 the difference between both intensities is higher than a  
 predetermined second threshold value. The second threshold  
 30 value is chosen such that the condition of step S24 will  
 not be fulfilled shortly after the start of the substance  
 entering the vessel system since the intensities will  
 continuously increase at that time. At some later time the  
 concentration of the fluorescent substance will come close  
 35 to a saturation, and differences between intensities of  
 subsequent images  $B(n)$  and  $B(n-1)$  will become smaller than

the second threshold value. This is indicative of a point in time at which the series of detected images should be terminated. The current value of the counter  $n$  is assigned to a variable  $n_{end}$  in a step S27, and the fluorescent imaging filter 83 is removed from the beam 74 and the thermal protective filter 85 is inserted in beam 74 in a step S29.

Thereafter the processing is continued by repeatedly displaying the detected images with displays 69 or 51. For this purpose the counter  $n$  is set to the value  $n_{start}$  corresponding to the start of the series of images (S31), in which  $B(n)$  is displayed (S33), and the counter  $n$  is incremented (S35). If a present value of counter  $n$  is below the value  $n_{end}$  thereof at the end of the series of images in a step S37, processing is continued at step S33. Otherwise it is decided in a step S39 whether button 97 was again operated for indicating an end of the procedure (S39). If the end of the procedure is not indicated, processing is continued at step S31 for displaying the series of images again.

While the above illustrated embodiment uses one single light source for generating the light beam illuminating the object with visible light and for exciting the fluorescence, a further embodiment may use different light sources for generating the visible light and the excitation light, respectively. The light source generating the excitation light may then be switched on and off according to the application.

A further embodiment may include two or plural light beams generated by one single light source or separate light sources wherein each beam includes the visible light and the excitation light.



In the embodiment illustrated above with reference to figures 1 to 3 the microscopy system 1 uses filters 84 and 85 which are transmissive filters. An alternative embodiment may use corresponding reflective filters which may be provided by a suitable coating of reflector 72 of the light source or which may be provided by separate reflectors with desired filter characteristics which separated reflectors may be inserted in the beam path with an actuator under control of controller 35.

10

In the embodiment illustrated above with reference to figures 1 to 3 the microscopy system 1 with its filters 57, 84 and 85 and filter characteristics shown in figures 2a, 2b, 2c, respectively, is optimized for observing the fluorescence of indocyanine green. In alternative embodiments the above illustrated principles may be applied to an observation of alternative fluorescent substances by adapting edges 90 and 61 of characteristics 89 and 58 to the corresponding excitation wavelengths and fluorescent wavelengths of the alternative fluorescent substance.

20

Figure 4 schematically illustrates a beam path of a further embodiment of a microscopy system 1. The microscopy system comprises an objective lens 3 having plural lenses 5 and 6. Lenses 5 and 6 are covered with antireflective coatings such that reflections of visible light at the surfaces of the lenses are reduced. The antireflective coating may be designed such that also reflections of infrared light and near infrared light at the lens surfaces are reduced.

30

Objective lens 3 receives a divergent beam 9 emanating from an object plane 11 of the objective lens 3. The diverging beam 9 is transformed by the objective lens to provide a substantially parallel beam downstream of the objective lens. Downstream of the objective lens 3 and above the objective lens in the representation of figure 4 there are

35

provided two zoom systems 13 and 14 which are schematically indicated in figure 4. Each zoom system 13, 14 uses a partial beam 15, 16, respectively and supplies the same to oculars 17, 18, respectively of the microscopy system. A user may perceive a magnified sharp image of object plane 11 by looking into the oculars 17 and 18 with his right and left eyes, respectively. Visible light is used for generating these images of the object plane 11. For this purpose, the object plane 11 is illuminated with visible light supplied by an illumination system 21 comprising a xenon lamp 23 and beam shaping lenses 24 and 26.

The microscopy system 1 further comprises a camera 35 for detecting a substantially sharp image of the object plane with visible light. The camera 33 comprises a CCD camera chip 35 having a light sensitive substrate positioned in an image plane 37. A beam splitter 29 is provided in the partial beam 16 for branching off a beam 31 therefrom and for supplying beam 31 to a camera adapter optics 39 supplying the beam 31 to the camera such that the substantially sharp image of the object plane 11 is generated at the image plane 37. The images detected by camera 33 may be used for documentation or they may be displayed by a display apparatus for displaying the image of the object plane 11 for users who may not directly use the oculars 17, 18. The images of camera 33 may be in particular supplied to a head mounted display of a user.

The microscopy system 1 comprises a camera 41 for detecting images of the object plane with infrared light. Camera 41 comprises a CCD camera chip 43 having a light sensitive substrate positioned in an image plane 45. A camera adapter optics 47 is provided for supplying a beam 51 branched off from the partial beam 51 by a beam splitter 49 to the CCD camera chip 43. The camera adapter optics 47 is configured such that a substantially sharp image of the object plane

11 is generated in image plane 45 with infrared light. Thus, the cameras 33 and 41 differ from each other in that camera 33 generates a substantially sharp image of the object plane 11 with visible light, and camera 41 generates  
5 a substantially sharp image of the object plane with infrared light. According to one conventional definition the infrared light may comprise wavelengths in a range of 820 nm to 870 nm.

10 A filter 53 is disposed in beam 51 in front of camera 41. Filter 53 is adapted to the fluorescent substance which is used in the application. In the present example the filter 53 is adapted to the fluorescence of indocyanine green such that it transmits substantially only light of a wavelength  
15 range between 820 nm and 870 nm. The fluorescent wavelengths of indocyanine green are within this wavelength range.

According to an alternative embodiment the beam splitter 49  
20 may be covered with a suitable coating such that the beam splitter 49 deflects only infrared light.

Images detected by camera 41 are supplied to a controller or computer 55.

25 In an application according to one embodiment a tissue to be inspected, such as a human liver is positioned in the object plane 11. Blood vessels extending through the tissue are substantially not visible if the tissue is observed by  
30 just using the visible light images provided by oculars 17 and 18. It is not easy to discriminate between blood vessel and surrounding liver tissue from such images. After an intravenous injection of ICG the fluorescent substance will accumulate in the vessels at a higher concentration than in  
35 surrounding tissue. An image of the tissue using light in the wavelength range of 820 nm to 870 nm will show higher

intensities at locations corresponding to fluorescent vessels as compared to surrounding tissue.

5 An example of an image detected by camera 41 and supplied to controller 55 is schematically illustrated in figure 5a. A major portion 57 of an imaging field 58 shows a very low intensity. A portion 59 shows a slightly higher intensity, and two portions 61, 62 show even higher intensities. Within portion 61 there is located a portion 63 showing an  
10 even higher intensity of infrared radiation. It is assumed that the portions 62 and 63 are associated with blood vessels, whereas the portion 57 is associated with surrounding tissue. It is further assumed that the portion 59 is associated with surrounding tissue in which some low  
15 concentration of fluorescent substance has accumulated.

The microscopy system 1 further comprises a display system 65 comprising an LCD chip 69 positioned in a plane 67. An image displayed with LCD chip 69 is superimposed with  
20 partial beam 15 by a projection optics 71 and a beam splitter 73. When looking into the ocular 17 the user may perceive a superposition of the visible light image of the object plane and an image representation generated by display 65. The controller 55 may supply an image to  
25 display 65 as it is schematically illustrated in figure 5a. The image displayed and perceived the user with visible light of e.g. blue color. Thus, the user is provided with a visible representation of the infrared image in a superposition with the visible light image. The user may  
30 then recognize blood vessels positioned within the object field of the microscopy system 1.

However, the superposition of the visible light image with the image according to figure 5a would result in a  
35 reduction of the information which may be gained from the visible light image within portions 61 and 62 since these

portions are indicated in blue color. To improve this situation the controller 55 performs an analysis of the images received from camera 41. The controller determines those coherent portions of the image showing intensities above a predetermined threshold. Using a suitable predetermined threshold a discrimination may be made between blood vessels and surrounding tissue. In the example shown in figure 5a the threshold will be adjusted such that the intensity in the portion 59 is below the threshold, and such that the intensities within portions 62 and 63 are above the threshold.

After identifying the coherent portions exceeding the threshold the controller 55 will determine peripheral lines surrounding the coherent regions. Such peripheral lines are associated with a boundary between the coherent portions and the surrounding portions of the image. The controller 55 supplies data representing the peripheral lines to the display 65. The display generates an image of the peripheral lines, and such image is superimposed with the visible light image as schematically illustrated in figure 5b. In the image, only the peripheral lines 75 of portions 61 and 62 are shown in blue color. Thus, the user is provided with the information relating to the blood vessels which are located in an interior of the peripheral lines 75, and the user may still perceive the visible light image of the blood vessels as usual, and he may perform a surgical treatment of these blood vessels while observing the visible light image thereof.

A filter 77 is disposed in a beam path of illumination system 21. Filter 77 is substantially not transmissive for wavelengths of the fluorescent emission of the fluorescent substance. The object will not be illuminated with fluorescent light such that the fluorescence of the

substance is visible in the images detected by camera 41 with a relatively high contrast and low background.

5 Additionally, a filter chopper 79 is disposed in the beam path of the illumination system 21. The filter chopper 79 is rotatably driven by a motor 89 which is controlled by controller 55. The filter chopper comprises plural sectors which are subsequently transmissive and non-transmissive for light at wavelengths in a range between 750 nm and  
10 820 nm. All sectors of the filter chopper 79 are substantially transmissive for visible light. The excitation of the fluorescent substrate is modulated by rotating the filter chopper 79. The intensities of the fluorescent images detected by camera 41 are modulated in  
15 time, accordingly, and the controller 55 may analyze the time dependency of the fluorescent image by a method such as a lock-in method for further reducing noise and background in the fluorescent image.

20 An alternative embodiment of the illumination system illustrated above is indicated by dashed lines in figure 4. The alternative illumination system 90 comprises a light source 91 separate from light source 23. Light source 91 is provided for illuminating the object with visible light,  
25 whereas light source 23 is only provided for generating the excitation light of the fluorescent substance. Thus, the illumination with visible light is independent from the illumination with excitation light, and a rotation of the chopper wheel 79 may not modulate the illumination with  
30 visible light which modulation might disturb the user in observing the visible light image of the object. According to a further embodiment the light source 23 is a laser light source which is rapidly switched on and off by the controller 55 for modulating the excitation light. The  
35 light modulating chopper may be omitted in such embodiment.

The microscopy system further comprises an optical coherence tomography (OCT) apparatus 200 emitting an analyzing light beam 205 and directing the analyzing light beam 205 onto a beam scanner 260. Beam scanner 260  
5 comprises a mirror for directing the analyzing light beam onto the object plane 11 and to focus the analyzing light beam 205 onto the object plane. The beam scanner 260 is controlled by controller 550 for selecting the locations at which the analyzing light beam 205 is directed onto the  
10 object plane and to change those locations. The OCT apparatus 200 detects depth profile data of the object at the selected location and transmits the depth profile data to controller 55. OCT apparatuses are well-known from the art. Examples are given in US 5,493,109 and US 5,795,295,  
15 the full disclosure of which is incorporated herein by reference.

A function of the OCT apparatus 200 is shortly illustrated with reference to figure 6 below. The apparatus 200  
20 comprises a white light source 220 emitting radiation coupled into an optical fiber 230. A beam coupler 240 is provided for coupling the radiation into two optical fibers 250 and 270. One partial beam of fiber 270 is directed onto a reference mirror 290 through a lens 280. The partial beam  
25 of fiber 250 is collimated through a lens 251 as the analyzing light beam 250 and directed to the beam scanner 260. The beam scanner 260 directs the analyzing light beam 250 onto the object 255 to be inspected. Radiation of the analyzing light beam 205 received back from the object is  
30 supplied by beam scanner 260 in a reverse direction back to the OCT apparatus 250 and coupled into fiber 250. The radiation reflected back from mirror 290 is again coupled into fiber 270. The beam coupler 240 superimposes the radiation received from the object through fiber 250 and  
35 the radiation reflected back from mirror 290 through fiber 270 and couples the superimposed radiations into fiber 265.

Fiber 265 supplies the superimposed radiation to a photodetector 275. An output of the photodetector is demodulated by a demodulator 285 and transformed to computer readable data by an analog-digital-converter 295  
5 and supplied to the controller 55.

The detector 275 receiving the radiation from the object 255 and the mirror 290 detects a signal which is increased by interference if optical wavelengths of the two partial  
10 beams between the beam splitter 240 and their superposition at the beam splitter 240 are equal within a coherence length of the light source. For achieving such equal optical beam paths, the reference mirror 290 is  
displaceable in a direction indicated with arrow 291 in  
15 figure 6. By displacing the mirror 290 and recording the corresponding intensities detected by detector 275 it is possible to detect a depth profile of the object 255 at that location at which the analyzing light beam 205 is  
directed onto the object 255. Obtaining such depth profile  
20 is time consuming since the mirror 290 has to be mechanically displaced.

The controller 255 controls the beam scanner 260 to direct the analyzing light beam 205 to those locations on the  
25 object at which depths profiles should be recorded. The controller 55 limits the recording of depths profiles to only those portions or analyzing regions which have been previously determined by controller 55 from the fluorescent  
light image which are indicated by reference numeral 62 and  
30 63 in figure 5b.

The controller 55 controls the beam scanner 260 such that depth profiles are recorded at a plurality of locations positioned on straight lines 213 within portions 62, 63,  
35 wherein the straight lines 213 are vertically arranged in the visible field 58 and disposed at a predetermined



distance from each other. The depth profiles recorded along lines 211 are displayed on a display 207 of the microscopy system 1. A keyboard 209 or other input means, such as a mouse, may be used for selecting the configuration of the straight lines 213 within the visible field 58, such as an orientation thereof and distance from each other. Further, one of portions 62, 63 may be selected such that depths profiles for the selected portion are not shown on display 207.

10

It is also possible to display some selected of the depths profiles by imaging system 65 and to superimpose such representations with the visible light image perceived through the ocular such that the user may analyze the depth profile while observing the image of the object through the ocular.

15

In the above illustrated embodiments indocyanine green is used as the fluorescent substance. However, other fluorescent substances may be also used. In particular, an auto-fluorescence of substances of the human body may be observed. As an alternative or in addition to the analysis of intensities of fluorescent images, also fluorescent half times may be analyzed for discriminating fluorescent regions from each other within the object field.

20

25

According to further embodiments the image generated by display apparatus 65 is coupled into partial beam 16 rather than partial beam 15. Alternatively corresponding representations may be coupled into both partial beams.

30

In the preceding embodiments the peripheral lines 75 are represented as full lines. According to further embodiments, the peripheral lines may be represented as broken lines, dotted lines, dot-dashed lines or other types

35

of lines, or the interior of the coherent portions may be represented as a shaded or hatched region of the image.

5 Therefore, while the present invention has been shown and described herein in what is believed to be the most practical and preferred embodiments, it is recognized that departures can be made therefrom within the scope of the invention, which is therefore not be limited to the details disclosed herein but is to be accorded the full scope of  
10 the claims so as to embrace any and all equivalent methods and apparatus.